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Fluid Mud in Energetic Systems: FLUMES II

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LONG-TERM GOALS

The goal of this research is to develop greater understanding of the dynamics of fluid mud and its role in the transport and deposition of sediment in coastal environments and on the continental margin. In particular, we seek greater understanding of the processes that influence the formation and maintenance of fluid mud in energetic environments.

OBJECTIVES

The research is a process-based study that addresses three primary objectives:

- Determine controlling factors in the formation and destruction of fluid mud under a sheared flow
- Verify Richardson number dependence for suppression of turbulence and carrying capacity of a high-concentration suspension
- Evaluate effects of mixed grain size on high-concentration suspensions

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APPROACH

To evaluate the controls on fluid-mud formation and the influence of sediment-induced stratification on flow, in situ measurements of vertical gradients of velocity, -sediment concentration (SSC), and fluid density throughout the water column, including the fluid mud are necessary. In addition to these parameters, the thickness of the fluid mud through accelerating and decelerating flows must be measured.

The Peticodiac River located in the Upper Bay of Fundy was selected as the study site. The Peticodiac Estuary is a macro-tidal environment that has been modified by the construction of a causeway in the late 1960s. During construction, depositional rates downstream of the causeway were on the order of 1 cm day^{-1} resulting in a decrease in the cross-sectional area of up to 90% within one year of closure. Maximum tidal currents are now on the order 2 m s^{-1} and suspended-sediment concentrations regularly exceed 10 g l^{-1} and can reach 300 g l^{-1} (Curran et al., 2004). At slack tide, sediment settles rapidly forming fluid mud layers on the order of 1-2 m thick.

The Peticodiac River Estuary now provides an ideal natural lab where the formation and destruction of fluid mud can be studied under a sheared flow with a quasi-steady current and without the complicating effect of waves. Measurements are carried out from a bridge that provides a solid framework for instrument deployment thus eliminating many of the challenges of shipboard operations in high-current environments. The Peticodiac has a distinct advantage over laboratory studies in terms of scale and avoids the practical issues of dealing with the quantities of mud required to create a fluid mud layer and maintaining flume equipment at these high concentrations of suspended sediment.

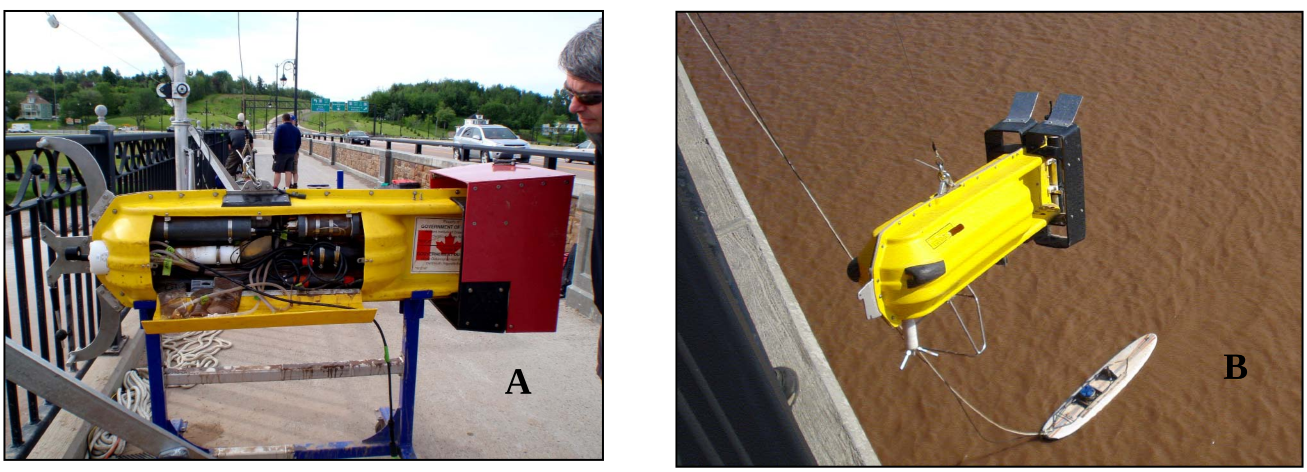

Figure 1: Photographs of the modified SUBS packages deployed in the Petitcodiac River. Left panel (A) shows the interior of SUBS I with the RBR CTD and sample bags exposed. The Marsh McBirney electromagnetic current meters are located on the front of the package near the railing and the OBS and sample port are situated on the opposite side near the front. The right panel (B) shows a SUBS modified to hold a Sontek ADV at the front, a D&A OBS5 in the center and a downward looking Nortek AquaDopp at the tail (SUBS II). Also seen in this panel is a surfboard with a 1.2 MHz RDI ADCP and dual frequency Knudsen sounder.

For water-column sampling in high flow conditions, a streamlined underwater buoyancy (SUBS) package designed at the Bedford Institute of Oceanography was modified for use as an instrument profiler (Fig. 1A; SUBS I). The addition of lead weights to the package in place of the normal buoyancy permits vertical profiling from a bridge at current speeds in excess of 1 m s^{-1}. A CTD and an optical backscatterance sensor (OBS) are mounted through the front and side of the package respectively. A sample port is co-located with the OBS and connected to a series of pumps to provide suspended sediment for OBS calibration and grain size analysis. Current shear was initially determined using two Marsh McBirney electromagnetic current meters (EMCMs) mounted 60 cm apart on the front of the CTD sampling package.In 2009 these measurements were augmented with the addition of a second SUBS package that was modified to accept a Sontek ADV, a D&A OBS5, and a Nortek Aquadopp profiler (Fig. 1B; SUBS II). To observe the formation of the lutocline and continuously monitor flow velocities, a dual frequency Knudsen echo sounder and an 1.2 MHz RD Instruments ADCP were mounted on a surfboard tethered to the bridge next to the location of the profiling package. In 2009 a second 1.2 MHz ADCP and a 2.5 MHz rotary sonar were deployed using a second surfboard (Fig. 2). The ADCPs and Knudsen echo sounder sample continuously, SUBS I (CTD/OBS/EMCMs/in situ samples) was deployed approximately every 30 minutes, and SUBS II (ADV/Aquadopp/OBS5) was deployed nearly continuously (every 15 minutes)..

Figure 2: Photo of the instrumented surfboards deployed from the bridge in the Petitcodiac River. Upper board consists of a 1.2 MHz RDI ADCP and a Dual Frequency (50 and 200 kHz) Knudsen sounder. The lower board has a 2.5 MHz rotary sonar and 1.2 MHz RDI ADCP mounted on it. The wake between the boards is caused by a SUBS package just below the surface.

All work is being conducted collaboratively between Tim Milligan and Brent Law of the Bedford Institute of Oceanography (BIO), Gail Kineke of Boston College (BC) and Alex Hay (Dalhousie). Technical support in 2009 was provided by BIO Co-op students Vanessa Page and Karen Devitt, Boston College students Michele Lermon (Masters) and Christie Hegermiller (undergraduate), and Dalhousie graduate student Richard Cheel.

WORK COMPLETED

The original SUBS profiling package was redesigned in 2008 to accept an RBR XRX-620 CTD and data logger, and a new control system was developed for the pump samplers. A second SUBS was modified to accept a Sontek ADV, a D&A OBS5 through the bottom of the package and a downward looking Nortek AquaDopp profiler was mounted on the tail. A 2.5 MHz rotary sonar and a 1.2 MHz RDI ADCP were mounted on a second surfboard.

The 2009 experiment was conducted from June 17-22, 2009. From June 17-21, conditions were dominated by tidal flow with very low fresh water input. On June 22 fresh water was released from the control structure as part of a fish migration strategy. Conditions after June 22 were dominated by fresh water flow with salt water intrusion only occurring towards the end of the flood.

Initial casts with the CTD/OBS SUBS package were made just prior to the passage of the tidal bore and continued approximately every 30 minutes until water levels during the ebb were less than 1 m. The ADV/OBS5/AquaDopp SUBS was profiled nearly continuously over the tidal cycle with 1 minute integrated samples being collected approximately every 0.5 m.

Continuous observations of current speed and depth of the lutocline were made using the surfboard mounted ADCPs and the dual frequency Knudsen sounder. Problems with communication with the rotary sonar limited data recovery to a brief period when initially deployed.

Calibration of the OBS is accomplished using the in situ sediment samples that range from 170 mg l^{-1} to nearly 450 g l^{-1}. This calibration takes advantage of the non linear response of the OBS at concentrations greater than ~5 g l^{-1} that was demonstrated for fluid mud on the Amazon Shelf (Kineke and Sternberg, 1995). Data are being compared with the OBS5 data collected on SUBS II that uses two detectors for concentrations O(10s) g l^{-1}.

Disaggregated Inorganic Grain Size (DIGS) analysis for the suspended sediment samples was completed.

RESULTS

Conditions observed during the June 2009 experiment were similar to those in 2007. Initially the system was dominated by tidal flow which resulted in salinities ranging from 1 to 14 psu and near bottom SSC values in excess of 400 g l^{-1}. The passage of the tidal bore created mixed water column with SSC concentrations on the order of 30-100 g l^{-1} (Fig. 3). As current velocity decreases, a lutocline forms and near bottom concentrations increase rapidly to greater than 100 g l^{-1} (Figs. 3, 4). The dual frequency echo sounder and ADCP show good agreement on the rapid formation of the lutocline with an initial settling rate of ~6 cm s^{-1}. The fluid mud layer remains coherent throughout the ebb. After the release of water from the head pond on June 22(?), salinities were below 1 psu and maximum near bottom SSC values decreased to 52 g l^{-1}.

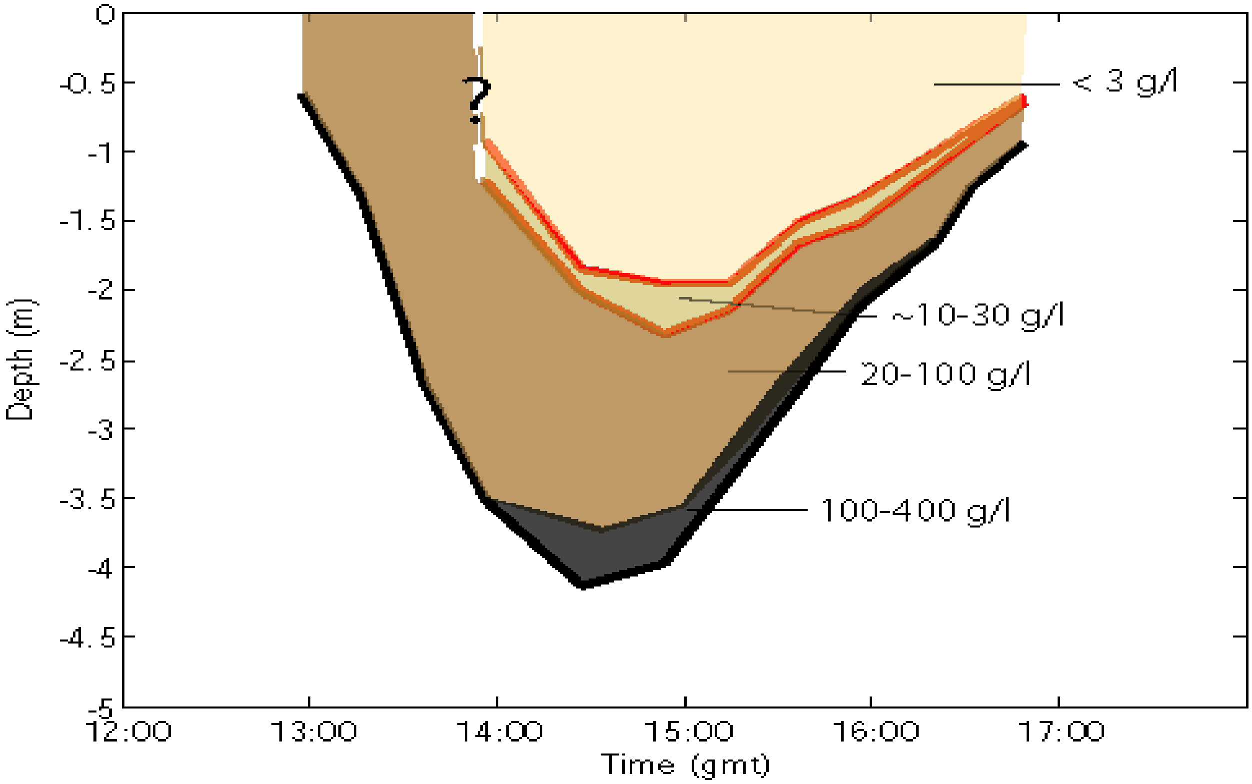

Figure 3: Contour plot of suspended sediment concentration determined from the in situ bag samples over a tidal cycle on June 21, 2009. Orange lines indicate the minimum and maximum depth of the lutocline defined by the change in slope of the OBS profile.

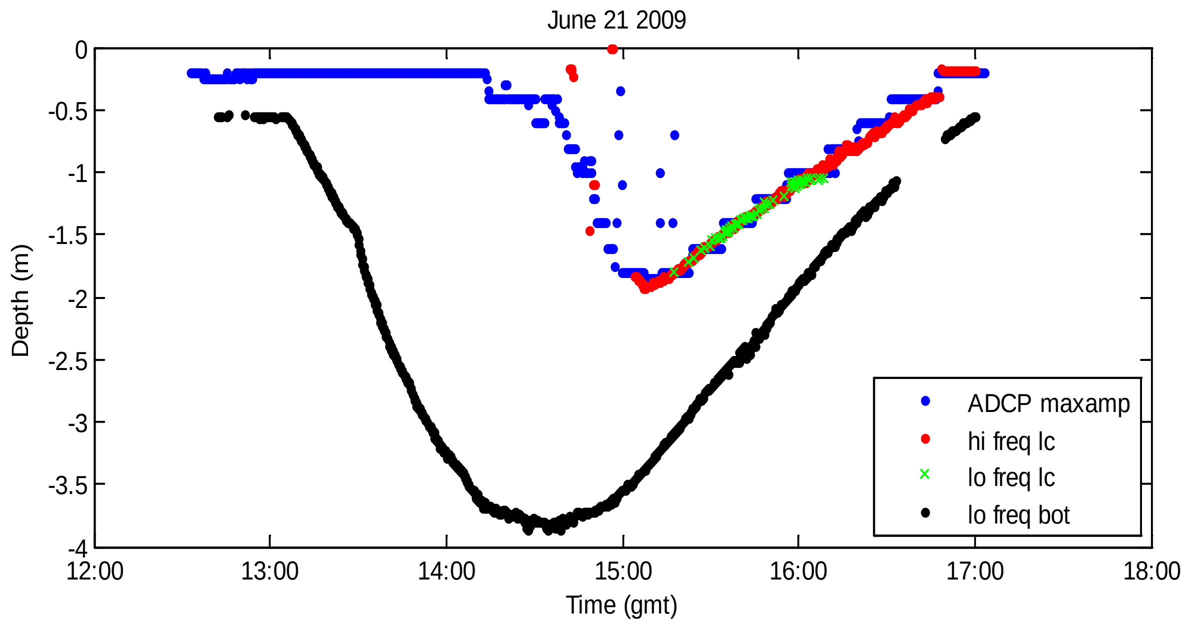

Figure 4: Plot of bottom and lutocline depths determined from the dual frequency Knudsen sounder and 1.2MHz ADCP. Black and green points show the maximum depth from the 50 kHz sounder and red points indicate the surface of the l;utocline from the 200kHz. Blue points are from the 1.2MHz ADCP.

Results obtained with the SUBS-mounted AquaDopp velocity profiler are shown in Figure 6. For each cast, SUBS II was lowered to the bottom and then retrieved, stopping for ca. 1 min at about 0.5 m depth intervals. The AquaDopp was mounted in a vertical orientation on the SUBS tailfin assembly with the transducer array just below the bottom of the SUBS. Data were collected over a 0.5 m profile starting at 0.4 m below the transducer assembly. These 0.5 m segments are evident in the velocity profiles in Figure 3, especially during the flood and turn to ebb.

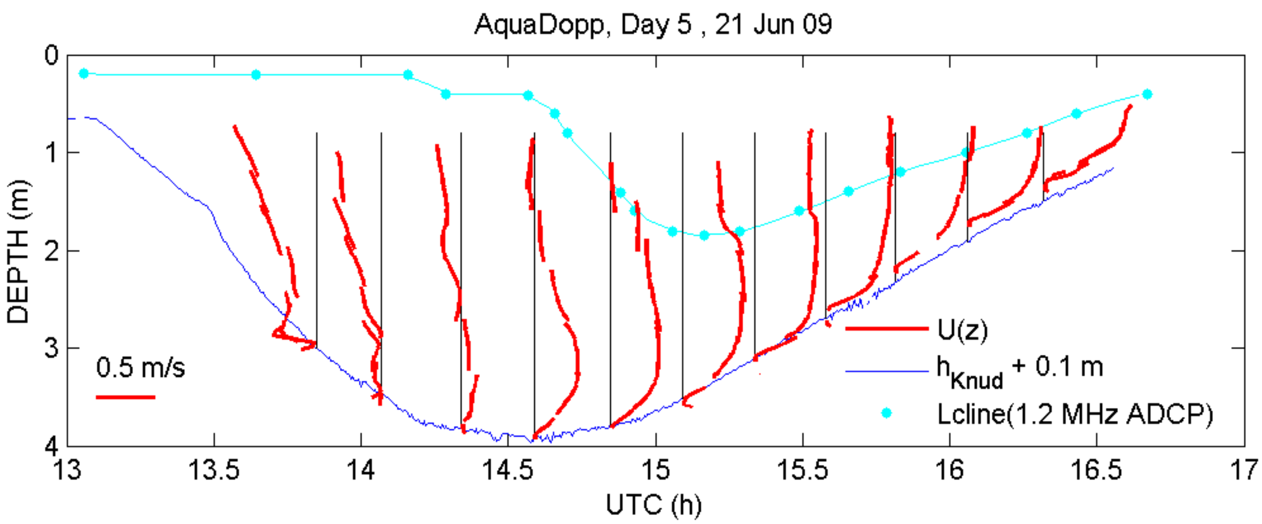

Figure 5. Profiles of along-channel velocity, U(z), obtained with the AquaDopp on 21 June 2009, in red. The vertical black lines indicate zero velocity and the time of the profile. Scale is indicated by the horizontal red bar. Water depth, as determined from the low-frequency channel on the Knudsen sonar, and offset in the vertical by +0.1 m, is indicated by the blue line. The lutocline depth, estimated from the amplitude of the surfboard-mounted 1.2 MHz ADCP (0.2 m bin size), is indicated by the cyan dots (the cyan line is a cubic interpolation between these points). Negative velocities indicate landward flow (i.e. flood tide) and positive velocities indicate seaward flow (i.e. ebb tide).

Similar to 2007, the DIGS of the sediment samples collected from June 17 – 21 showed that as current speed decreased all particles sizes in suspension were removed at an equal rate leading to rapid clearing of the upper water column and the creation of the fluid mud layer. During the freshwater discharge period the suspension was unflocculated and the size spectra for samples collected from the surface and bottom of the water column show only the coarsest material settling as flood current

velocities approached 0. Rapid flocculation at high sediment concentration is essential for rapid deposition and the formation of fluid mud (Hill et al., 2000; Milligan et al., 2007). Observations of the DIGS over the entire sampling period show an increase in coarse material near bottom that likely leads to the development of the silty base layer found in the tidalites located along the banks of the Petitcodiac.

IMPACT/APPLICATION

Our recent observations refine our understanding of current shear at the lutocline surface. These observations improve our understanding of the formation and maintenance of fluid mud in sheared flows and to further test threshold conditions for the suppression of turbulence and carrying capacity of

turbulent flows (Trowbridge and Kineke, 1994). Multiple measurements with different instruments provide a unique dataset on how acoustic instruments behave in high concentration sediment suspensions. Our data confirm the importance of salinity and sediment concentration in the formation of fluid mud layers and provide a basis for investigating the dynamics of these layers in macrotidal estuaries.

RELATED PROJECTS

G. Kineke is a co-PI on an ONR MURI project, "Mechanisms of Fluid-Mud Interactions Under Waves." This project includes investigators from Johns Hopkins (Dalrymple, Shen), Woods Hole Oceanographic Institution (Trowbridge, Traykovski), MIT (Liu, Mei,Yue) and Memorial University (Bentley). The major objective of this study is to examine the various mechanisms of water wave dissipation over muds and field, laboratory, and theoretical approaches will be employed.

T. Milligan is a co-PI on the ONR Tidal Flats project in Willapa Bay looking at sediment flux and its impact on sediment strength.

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